Libera Overview and Mission Status Update

P. Pilewskie, M. Hakuba & the Libera Science Team

Libera, NASA Earth Venture Continuity-1 Mission

'Li-be-ra, named for the daughter of Ceres in ancient Roman mythology

JPSS-3 Instruments

***Libera* – Earth Radiation Budget**

ATMS - Advanced Technology Microwave Sounder

CrIS - Cross-track Infrared Sounder

VIIRS – Visible Infrared Imaging Radiometer Suite

OMPS – Ozone Mapping and Profiler Suite

Libera completed Preliminary Design Review 8-10 Feb. 2022

Libera passed KDP-C 12 April 2022

Provides continuity of the Clouds and the Earth's Radiant Energy System (CERES) Earth radiation budget (ERB).

- Measures integrated shortwave (0.3–5 µm), longwave (5–50 µm), total (0.3–100+ µm) and ***(new) split-shortwave (0.7–5 µm) radiance*** over 24 km nadir footprint; ***uncertainty ~ 0.3%***
- ***Includes a wide FOV camera for scene ID and simple ADM generation to pave way for future free-flyer ERB observing system***

Innovative technology:

- ***Electrical substitution radiometers (ESRs) using vertically-aligned carbon nanotube (VACNT) detectors***

Primary operational modes:

- Cross-track and azimuthal scanning; on-board calibrators; solar and lunar viewing.

Flight:

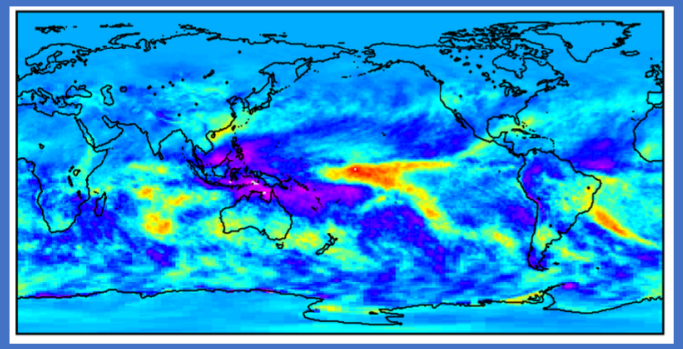
- **JPSS-3, 2027 launch; 5-year mission**

Partners:

- LASP, Ball Aerospace, NIST Boulder, Space Dynamics Lab; CU, JPL, CSU, UA, UM, LBL

Libera guided by the ERB Science Working Group Report

RECOMMENDED MEASUREMENT AND INSTRUMENT CHARACTERISTICS FOR AN EARTH VENTURE CONTINUITY EARTH RADIATION BUDGET INSTRUMENT



National Aeronautics and Space Administration

- Science Working Group formed February, 2018.
- Working Group consisted entirely of civil servants to avoid Federal Advisory Committee Act rules given time constraints.
  - 22 NASA and NOAA CS personnel.
- Goal of SWG to recommend instrument and measurement characteristics for a continuity-preserving instrument, within cost cap.
- Recommended solution was basically FM6, maybe with reduced scanning capability. (Cross track, with azimuthal rotation capability for lunar/solar calibration.)
- **Note: recommendations are not AO requirements!**
- SWG met periodically from February to August.
- First draft July 2018 published for public comment.
- Comments informed final draft.
- Final draft is complete.
- Final draft will be made available on NASA web site, and referenced in AO.

Recommended Observational Characteristics

- Should include onboard calibration
- Should conduct periodic solar and lunar calibration
- Instrument characterization and ground calibration traceable to NIST standards
- Class C with a 5-year nominal lifetime
- Should be within 15 min of a 13:30 local equator crossing time[1]
- *Minimum of 6 months overlap with at least one of the remaining CERES instruments*
- Should fly on the same satellite or within 3 min. of an imager with spatial resolution and spectral channels similar to VIIRS

[1] All CERES instruments except those on Terra are in an ascending sun-synchronous orbit with a 13:30 local equator crossing time

Recommended Measurement Characteristics

- Measurements: Earth-emitted longwave radiance (0.5% uncertainty) and Earth-reflected solar radiance (1.0%) over the three unique broad bands, 20-25 km nadir spatial resolution, daily full-global coverage:
  - Shortwave reflected solar radiation, 0.3 to 5 µm (0.17% [2])
  - Emitted longwave radiation, 5 to 50 µm (0.24% [2])
  - Total outgoing radiation: 0.3 to >100 µm (0.22% [2])

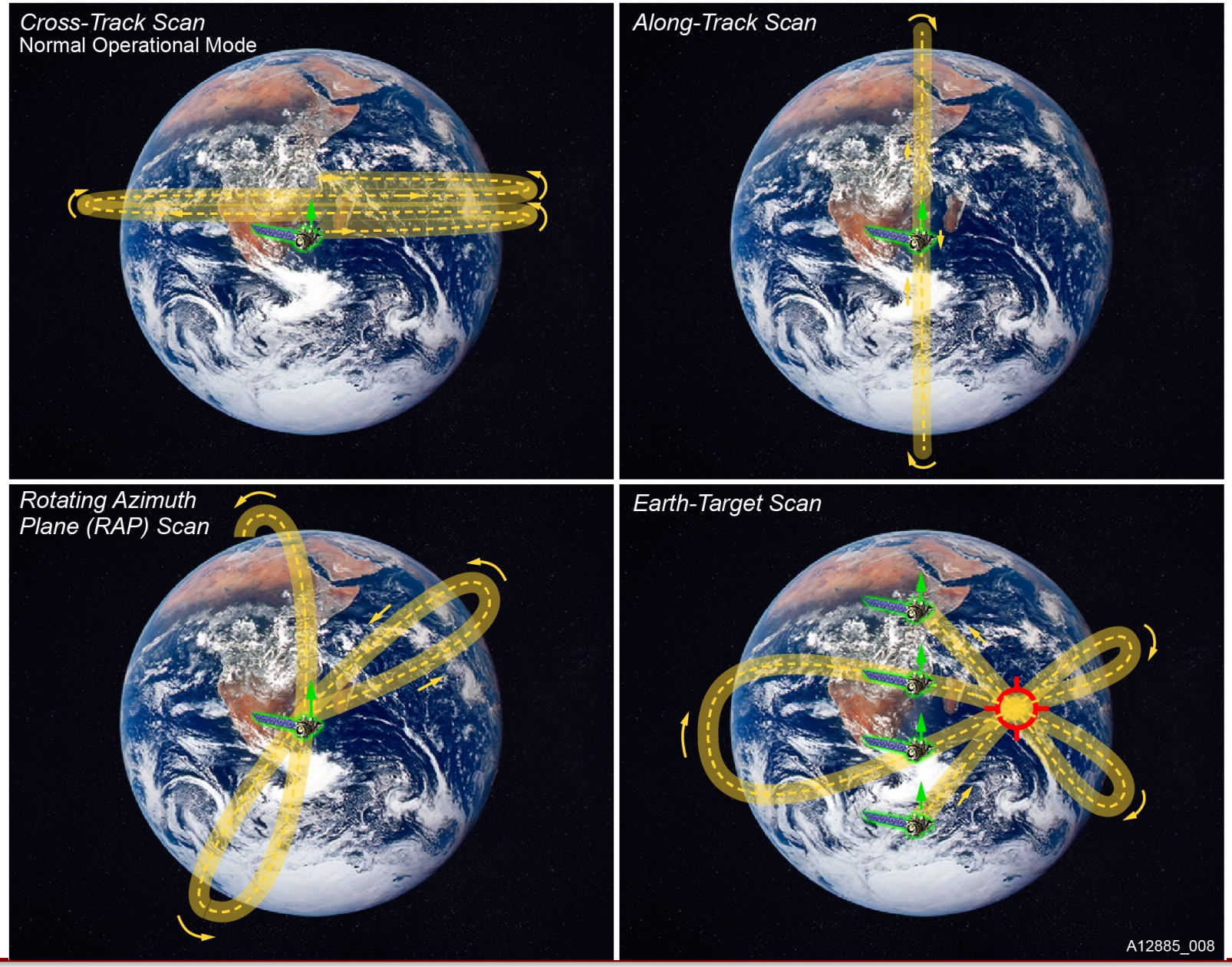
- CERES FM6 on NOAA 20 has the above three channels. These are the preferred channels in the science working group report.
- CERES FM1-FM5 does not have 5-50 µm channel but does have a window channel from 8-12 µm.
- Each instrument has independent and identical co-aligned and co-registered telescopes.
- Libera adds a split SW channel, 0.7–5 µm. (0.17% [2])

[2]Libera projected uncertainty

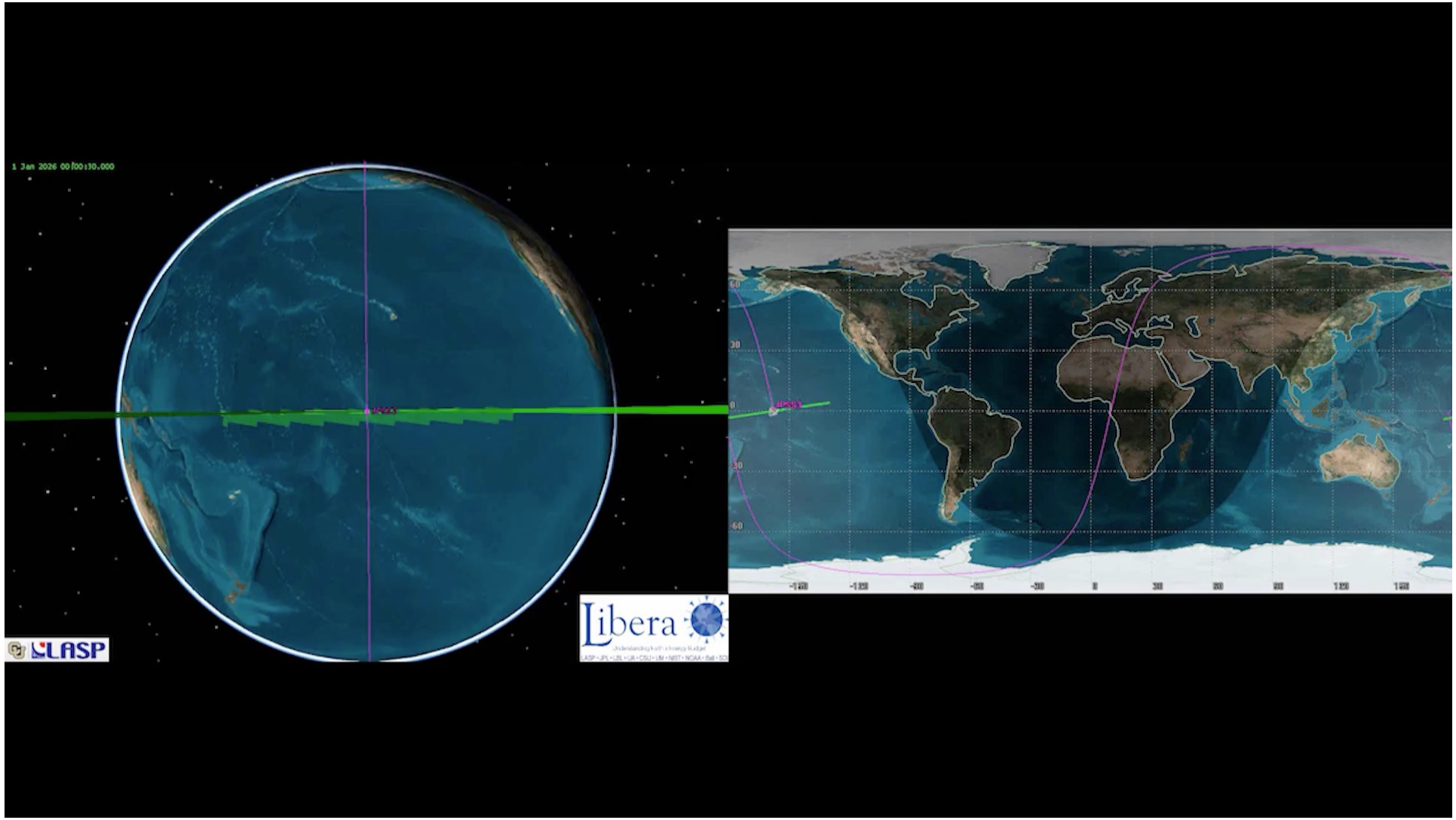
Libera Level-1 requirements

Requirement	Baseline Value	Threshold Value
Design Lifetime	5 years	5 years
Spectral Ranges	0.3 μm - 5 μm 0.7 μm - 5 μm 5 μm - 50 μm 0.3 μm – 100+ μm	0.3 μm - 5 μm 5 μm - 35 μm 0.3 μm – 100+ μm
Channel Accuracies (k=1)	SW: 0.17% Split SW: 0.17% LW: 0.24% Total: 0.22%	SW: 1% LW: 0.5% Total: 0.5%
Channel Precisions	0.11 $W/m^2/sr$ for all four channels	SW: 0.2 $W/m^2/sr$ LW: 0.45 $W/m^2/sr$ Total: 0.3 $W/m^2/sr$
Channel Stability	0.1%/decade	0.3%/decade
Channel Linearity	0.1% deviation over the dynamic range for all four channels	0.15% deviation over the dynamic range for all channels
Channel Dynamic Range	0 - 500 $W/m^2/sr$	0 - 500 $W/m^2/sr$
WFOV Imaging	wavelength 555 nm 20 nm bandwith 140° FOV 1 km horiz. Resolution at nadir 1.5% uniformity 5% radiometric accuracy 0.2 - 600 $W/m^2/sr/\mu m$ dynamic range 0.33 Hz frame acquisition	No requirement

Libera Operational Modes

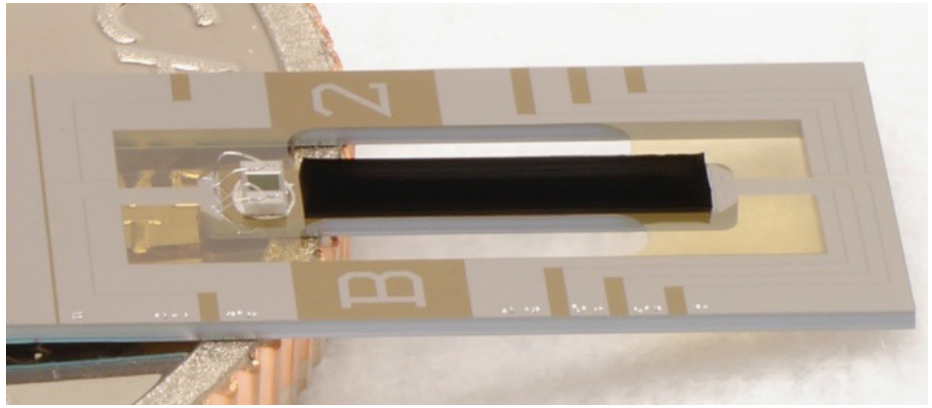


Global Coverage in <12 Hours

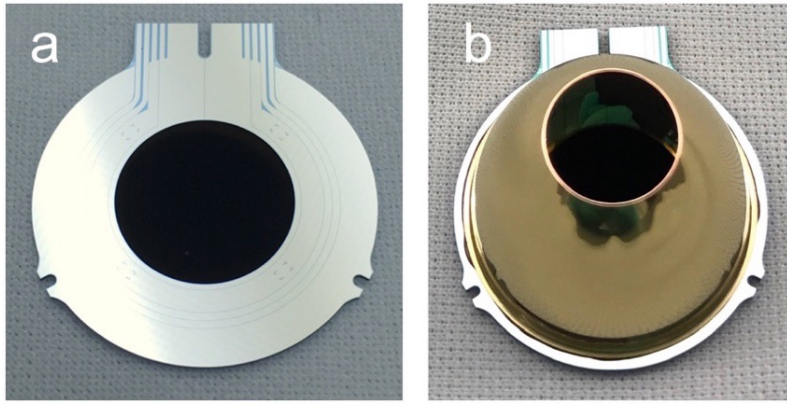


VACNT ESRs for Climate Studies

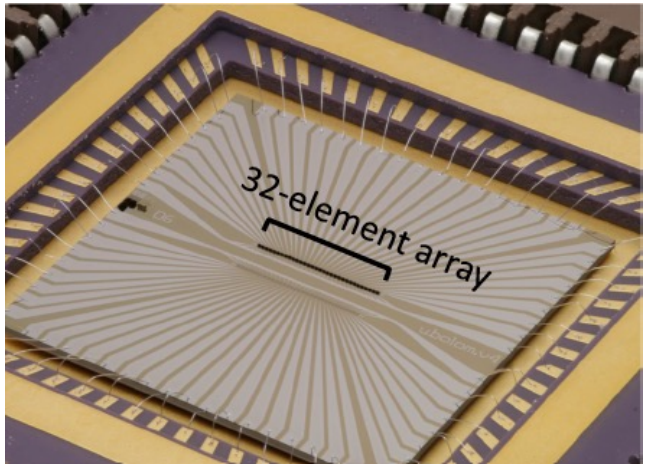
Compact Spectral Irradiance Monitor (CSIM)



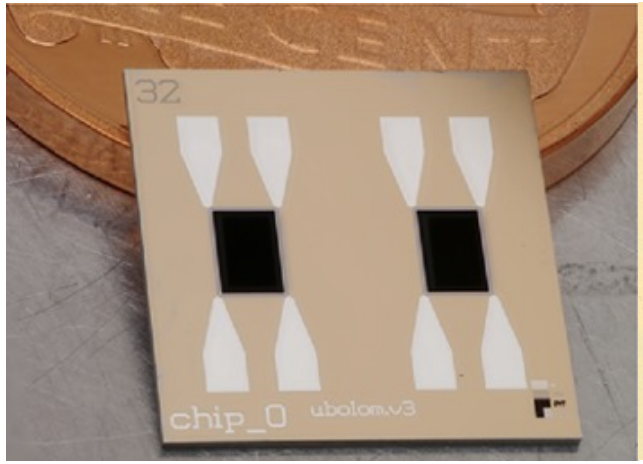
Compact Total Irradiance Monitor (CTIM)



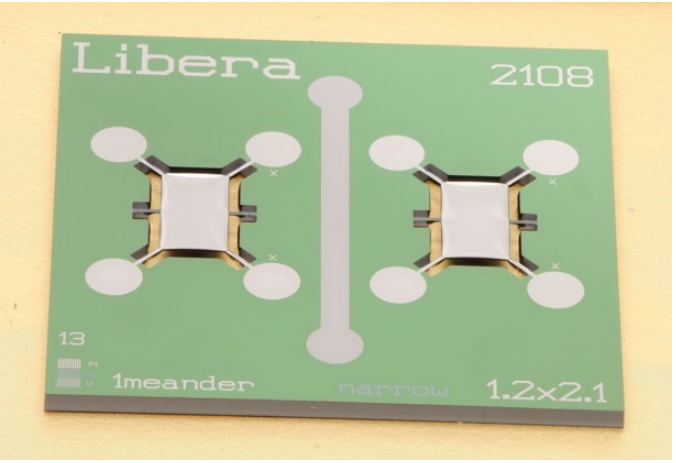
Black Array of Broadband Absolute Radiometers (BABAR)



Libera Prototype 0

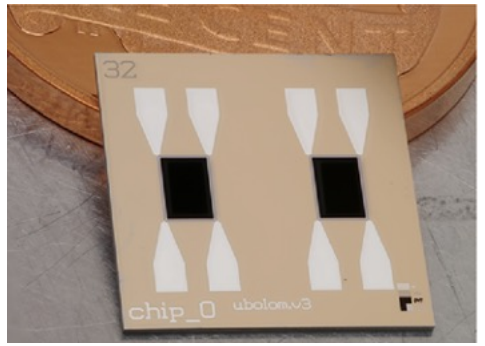


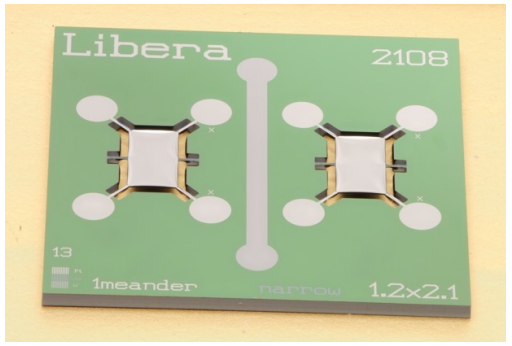
Libera Prototype 4



Pre-launch Calibration and Characterization

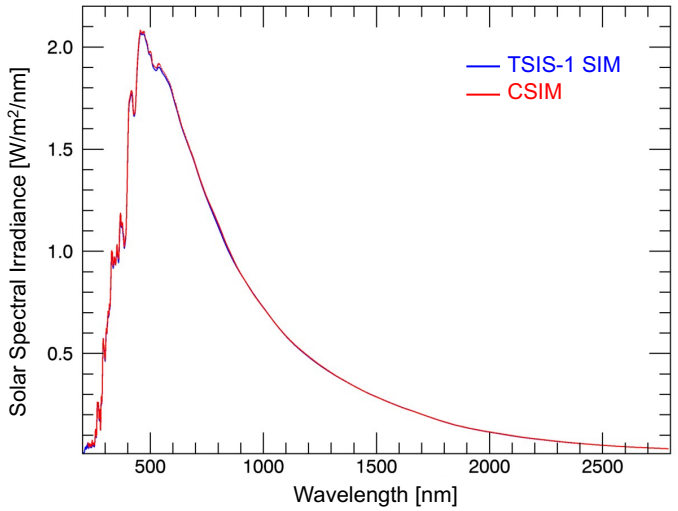
- Component-Level Characterizations
  - Properties of all optical surfaces (mirrors, filters, detectors) measured at NIST and PTB, Germany
  - Used in instrument model to generate expected spectral response functions
- Radiometer Calibrations
  - End-to-end channel calibration at LASP against NIST-traceable absolute irradiance standard detector
  - Uses laser tie-points from 300 nm to 16 µm and broadband blackbody sources.
- System Level Validation
  - Integrated system transported to SDL for independent validation using SW & LW targets at a facility developed for RBI





Libera utilizes advanced carbon nanotube detector technology developed by LASP and NIST over a number of ESTO projects: BABAR ACT, CTIM-FD, CAESR, and CSIM-FD.

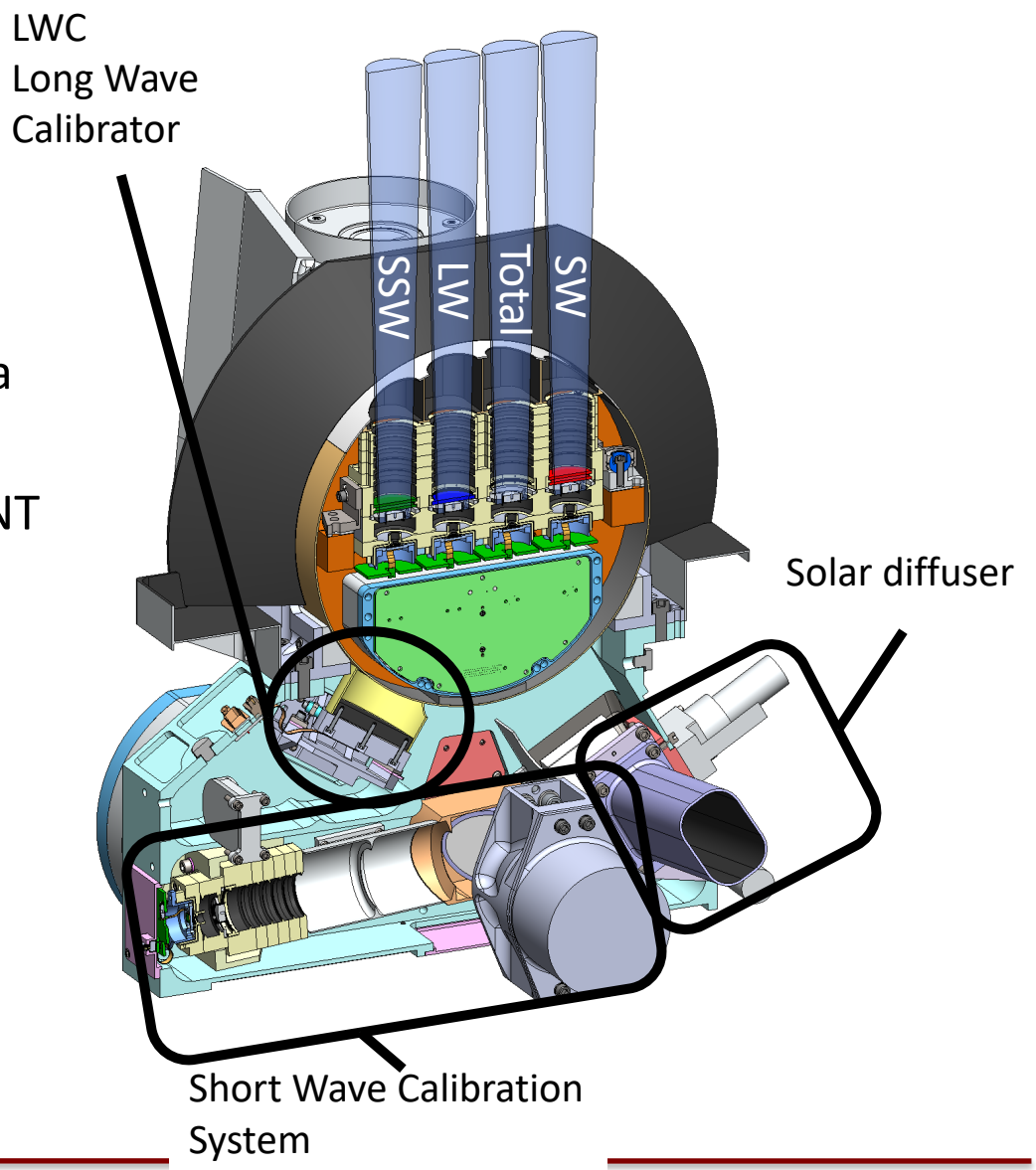
On-Orbit Demonstration of ESRs Using VACNTs



On-Orbit Calibration and Validation

A *belt-and-suspenders* approach:

- Onboard calibration targets (daily)
  - Shortwave calibrator using LED sources (365, 410, 520, 625, 810, 1550 nm) and engineered diffuser; stability tracked via a SW calibration radiometer
  - Longwave calibrator: flat-plate blackbody (310-330K) with CNT coating, Si-traceable PRTs to NIST standards.
- Solar calibrations (bi-monthly)
  - Three Spectralon diffusive panels viewed bi-monthly/monthly/semi-annually for degradation tracking
- Lunar calibrations (~ 8-12 per year)



Libera Science Goals & Objectives

Overarching goals:

1) Provide seamless continuity of the ERB measurement with characteristics identical to CERES

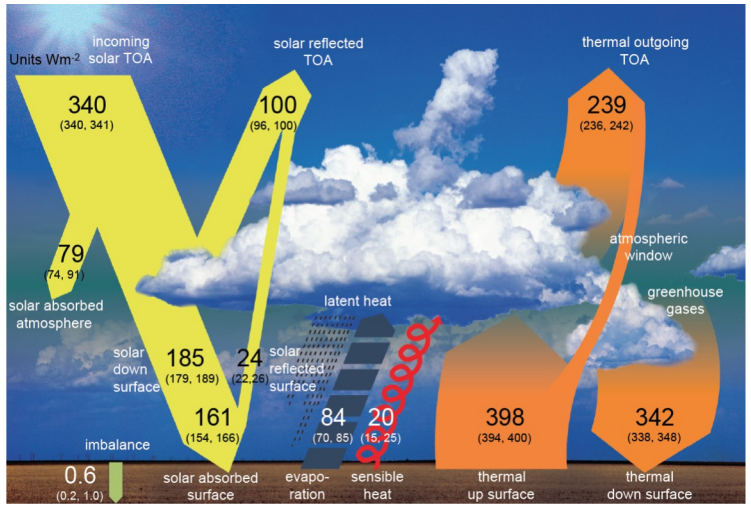
- Prevents gap in ERB data record critical for studies of global climate change
- Tied to **Science objective 1**: Use extended record to identify and quantify processes responsible for the instantaneous to decadal variability of ERB

2) Develop a self-contained, innovative, affordable observing system

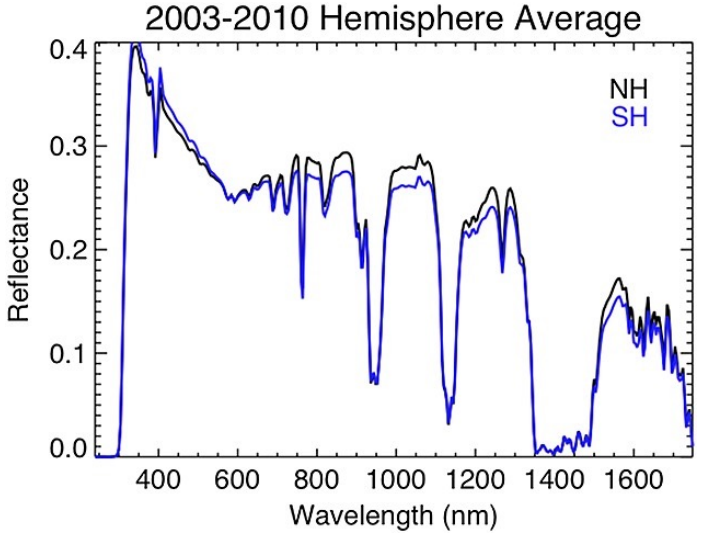
- Novel, miniaturized detectors greatly improve accuracy & stability and pave way toward smaller & cost-effective follow-on mission.
- **Science objective 2** *Libera* tests a miniature wide field-of-view camera to provide scene & angular context crucial for radiative flux retrieval

3) Provide new and enhanced capabilities that support extending ERB science goals

- Employ Split-Shortwave channel to derive SW VIS and NIR fluxes and quantify SW energy disposition
- Tied to **Science objective 3**: Revolutionize understanding of spatio-temporal variations in SW, VIS & NIR irradiance



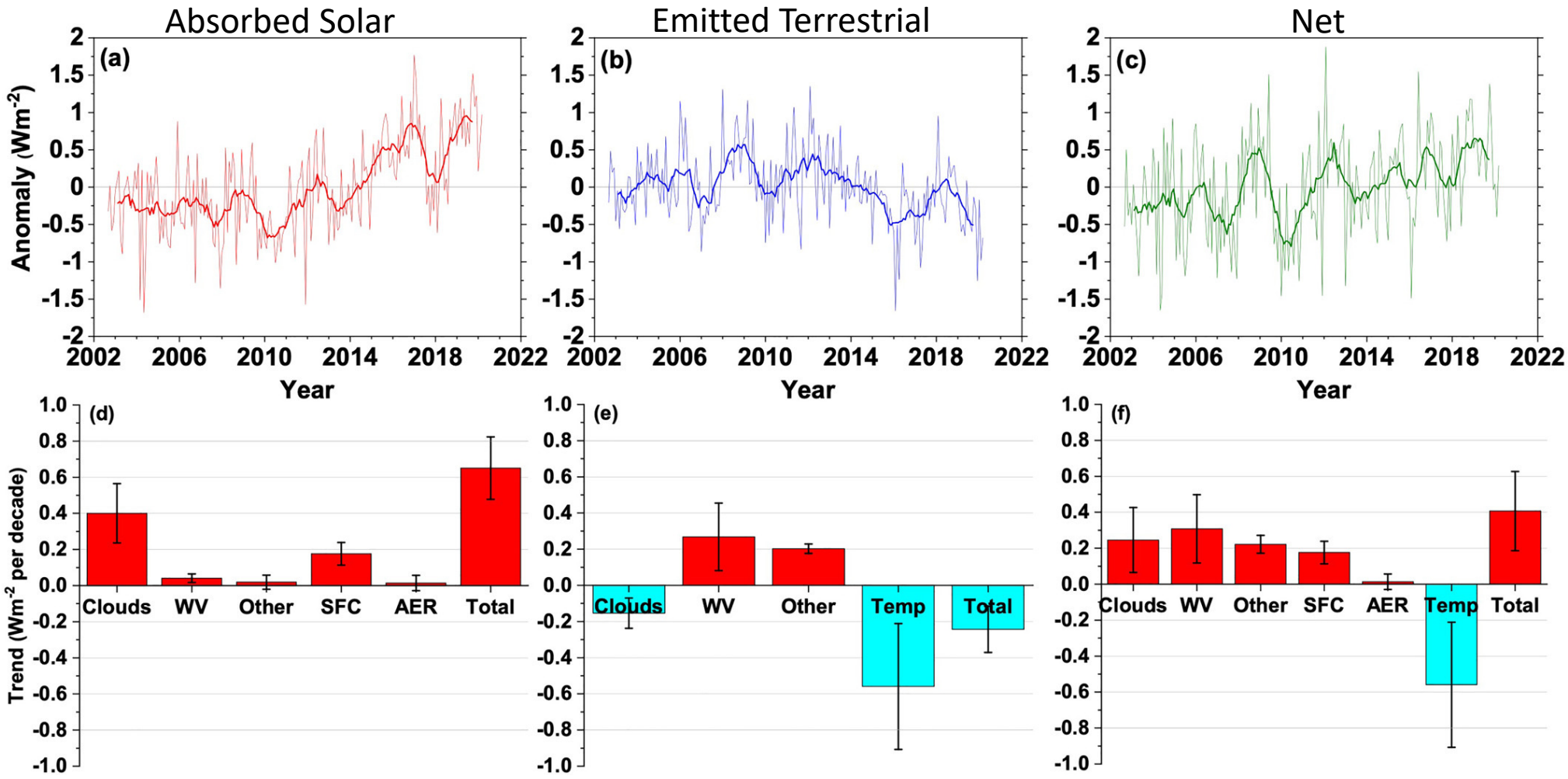
Hemispheric Albedo Symmetry?



CERES Short- and Long-wave Climate Data Records

Loeb et al., GRL, 2021, https://doi.org/10.1029/2021GL093047

Trend in net:
0.42 W m^{-2}/decade

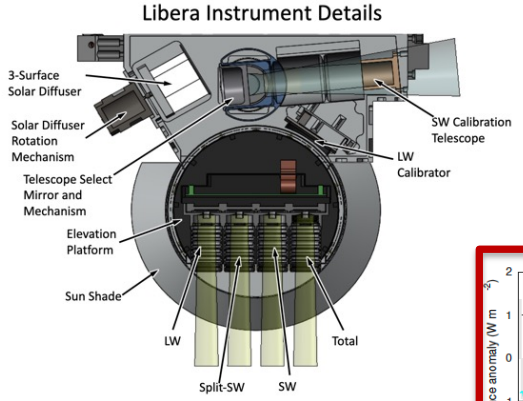


Libera's Split-shortwave Channel

- Libera's fourth channel measures near-IR radiances (0.7-5 μm) at the same accuracy as the total SW radiance (0.2%).
- ADMs for VIS (SW-NIR) radiance-to-irradiance conversion originate from RTM calculations, WFOV camera, and RAPS sampling
- NIR irradiance = SW – VIS irradiance

Science objectives:

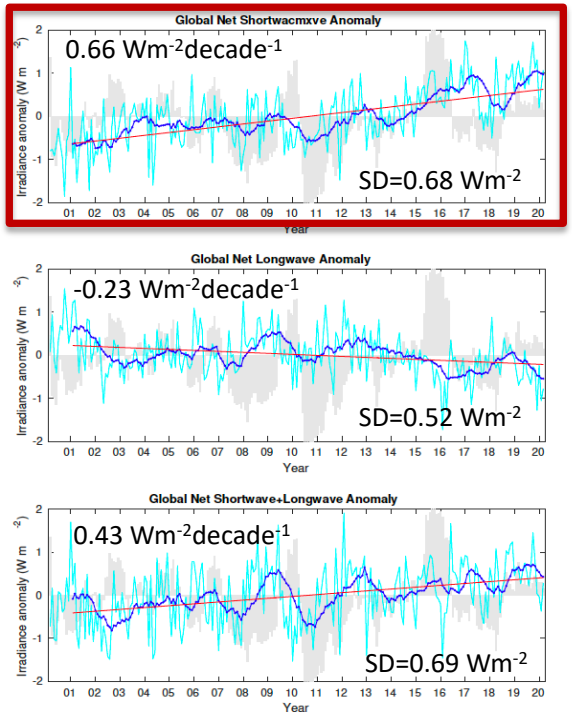
- **(1) NIR & VIS signature of processes controlling the absorption of solar radiation & climate feedbacks.**
- **(2) Better understand the hemispheric symmetry of planetary albedo.**
- Quasi-spectral model evaluation to reveal process-related and potentially compensating biases



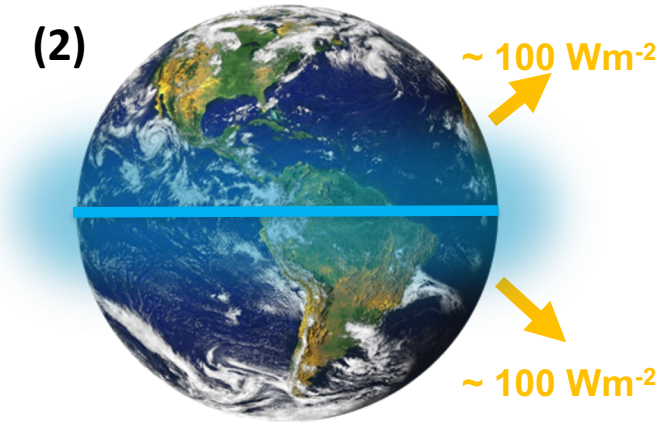
(1)

- **In CERES observations, a positive trend in ASR is the main reason for increase in EEI**
- **Climate models suggest that global warming is sustained by the increase in ASR on decadal to centennial time scales (positive SW feedbacks)**

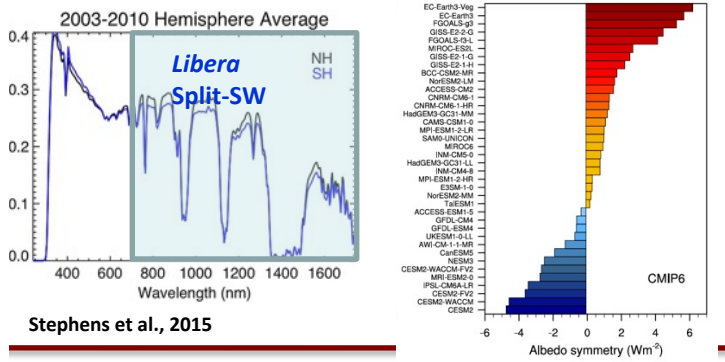
Stephens et al., 2022



(2)



Rugenstein & Hakuba, submitted



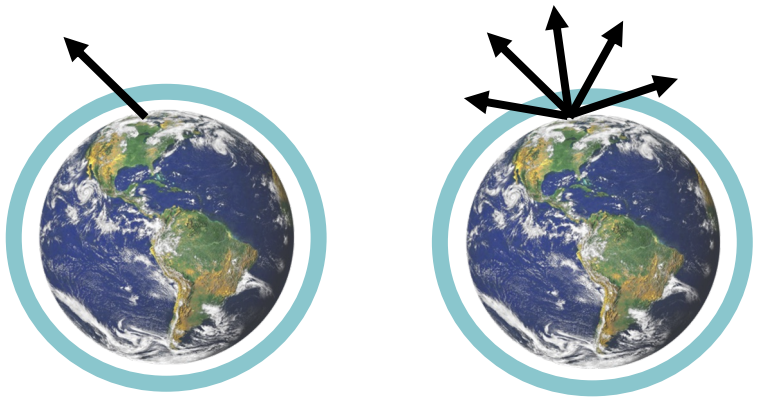
Stephens et al., 2015

Angular Distribution Models

ADMs for VIS and NIR do not exist.

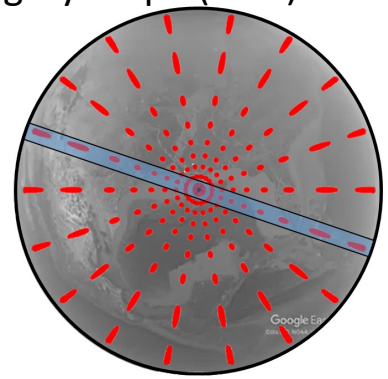
- Traditional ADM development takes years of measurements.
- Camera angular information accelerates ADM development.
- Single wavelength camera acts as a proxy for the split channels

$\frac{\pi L}{F}$ **= ADM for a certain scene type and viewing geometry**



Measured Radiance, L **Estimated Irradiance, F**

Camera ADM samples (red) and imagery stripe (blue):



Scene ID Experiment

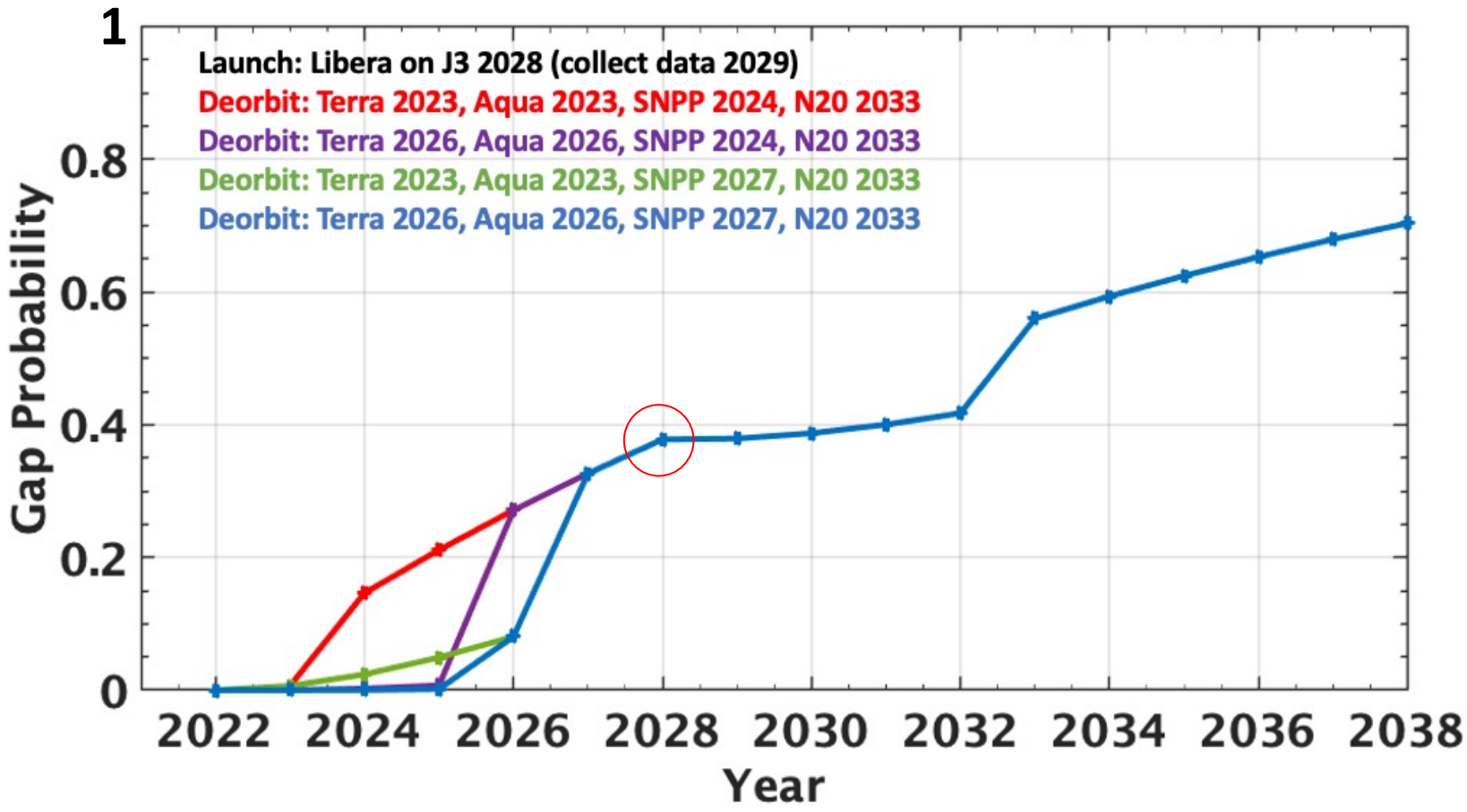
- Cloud fraction retrieval at 1 km to determine ERBE-like scene within Libera footprint.
- *Adaptative thresholding* over select surface types. (Sun et al, 2016).

ERBE SW scene types:

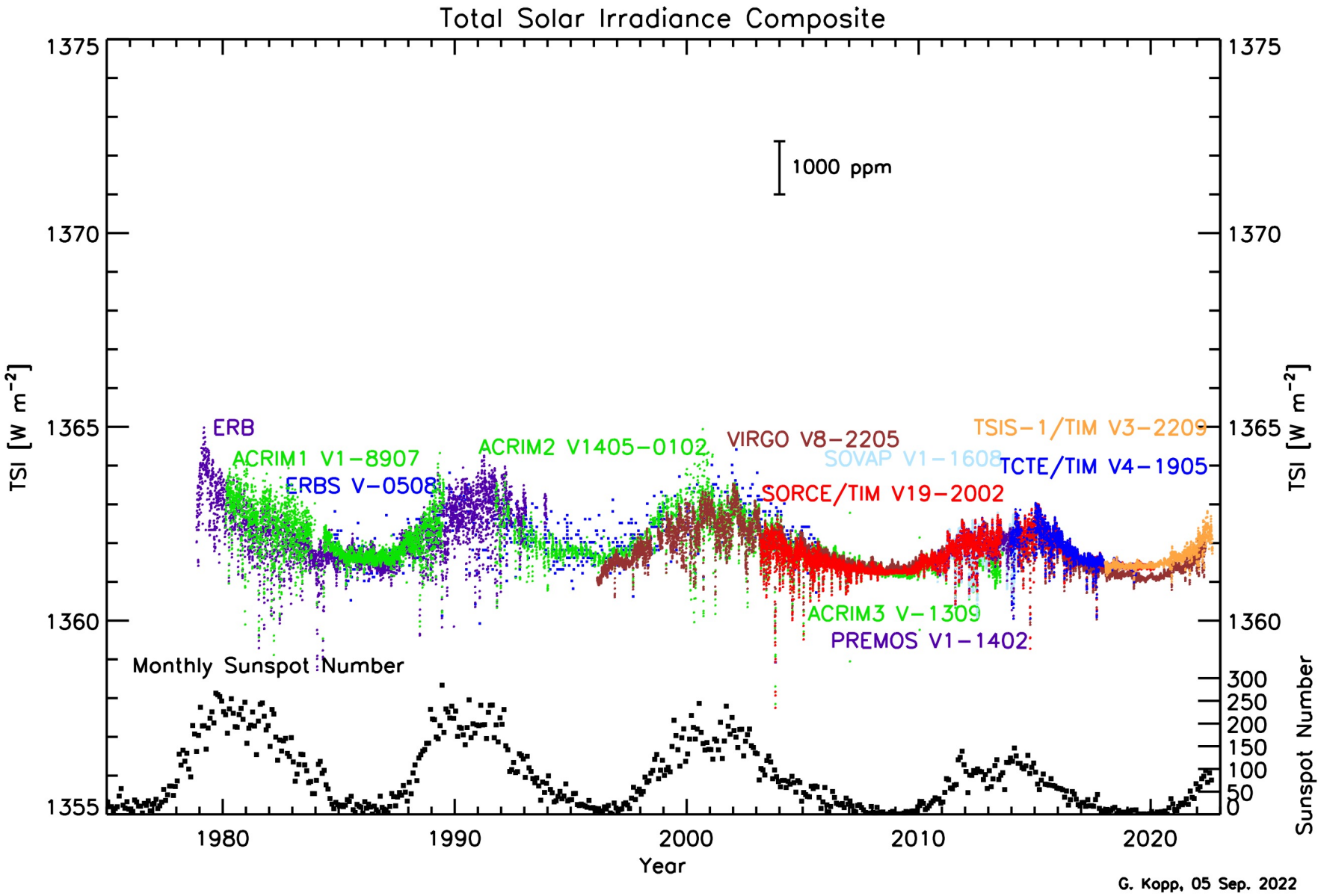
Scene ID Number	Cloud Fraction	Surface Type
1	Cloud-free (0–5%)	Ocean
2	Cloud-free (0–5%)	Land
3	Cloud-free (0–5%)	Snow
4	Cloud-free (0–5%)	Desert
5	Cloud-free (0–5%)	Land-ocean mix
6	Partly cloudy (5–50%)	Ocean
7	Partly cloudy (5–50%)	Land or desert
8	Partly cloudy (5–50%)	Land-ocean mix
9	Mostly cloudy (50–95%)	Ocean
10	Mostly cloudy (50–95%)	Land or desert
11	Mostly cloudy (50–95%)	Land-ocean mix
12	Overcast	All

ERB Continuity: Gap Risk Analysis

- By late 2027, there is a 38% probability of a gap
- Gap-filling methods using imagery data have uncertainty on the order of current decadal trends, 0.4 Wm^{-2}.
- The current ERB data record depends on continuity and overlap

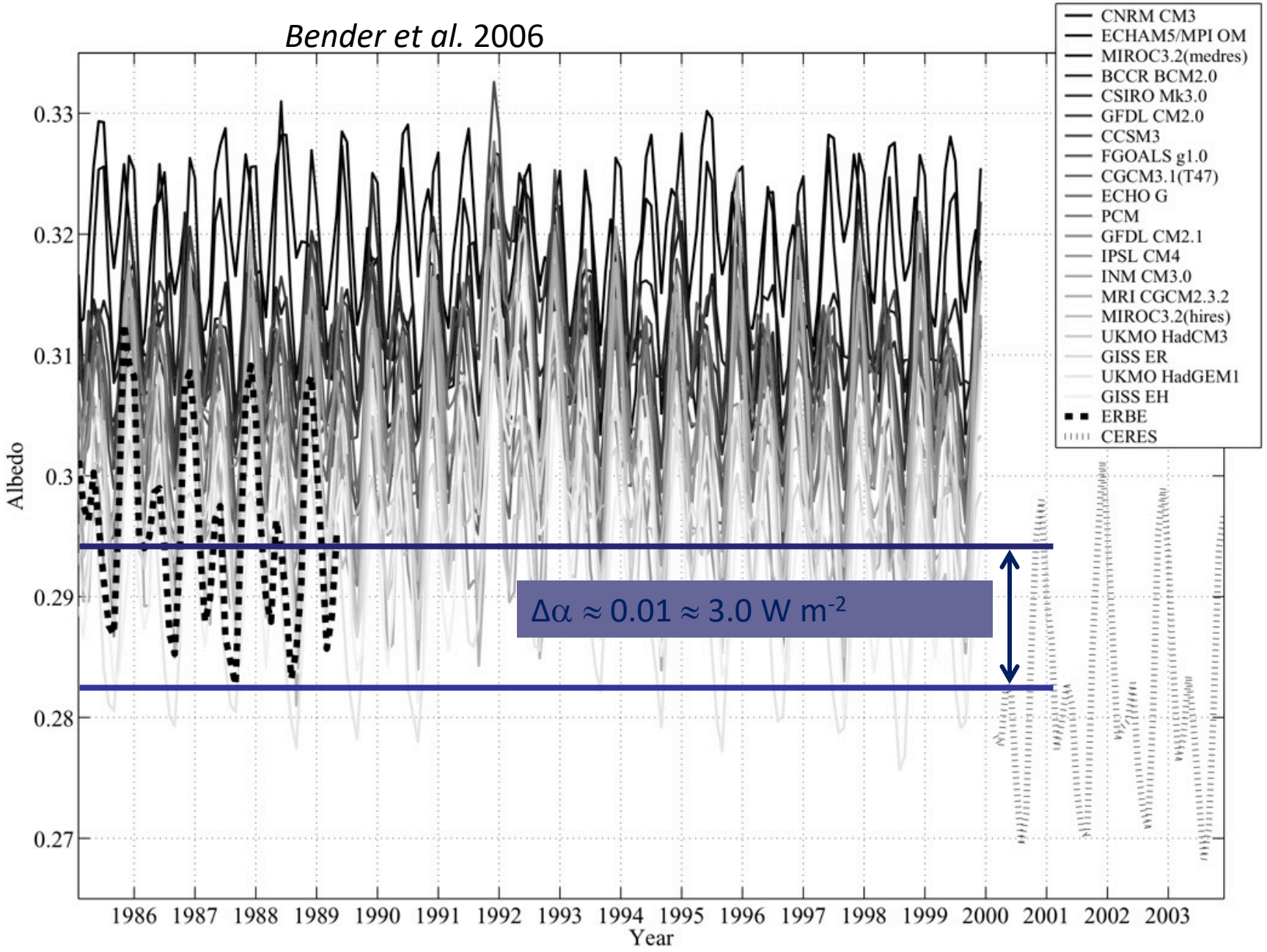


Total Solar Irradiance Data Record



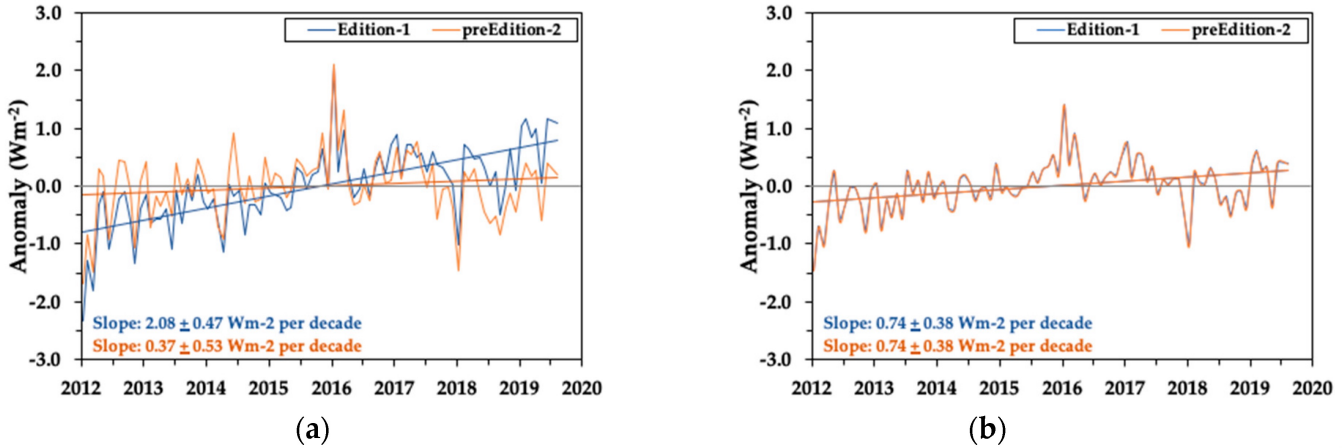
CERES vs. ERBE Albedo: Real Trend or Offset?

Bender et al. 2006

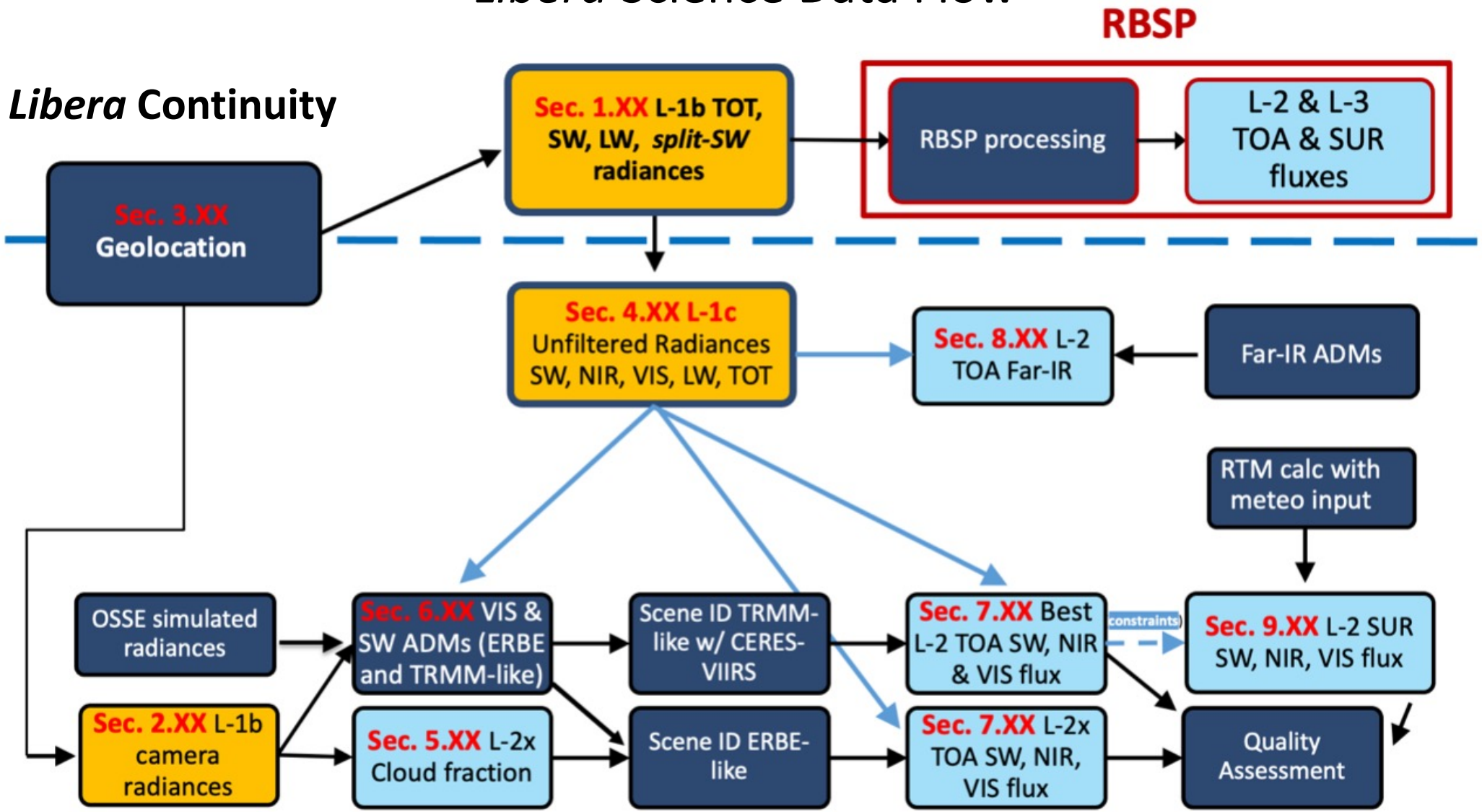


Generation of a Seamless Earth Radiation Budget Climate Data Record: A New Methodology for Placing Overlapping Satellite Instruments on the Same Radiometric Scale*; Mohan Shankar et al., Remote Sens. 2020, 12(17), 2787; https://doi.org/10.3390/rs12172787*

- New approach to tie the observations from CERES FM5 (SNPP) to FM3 (Aqua).
- Spatially and temporally matched footprints when their orbits cross
  - ➢ Determines the magnitude of radiometric scaling necessary.
- Constrained optimization approach to derive the spectral response functions
- Remarkable consistency between the observations from the CERES on Terra, Aqua, and SNPP.
- Radiometrically scaled data products for SNPP have been validated
  - ➢ publicly available as Edition-2 versions of data products.



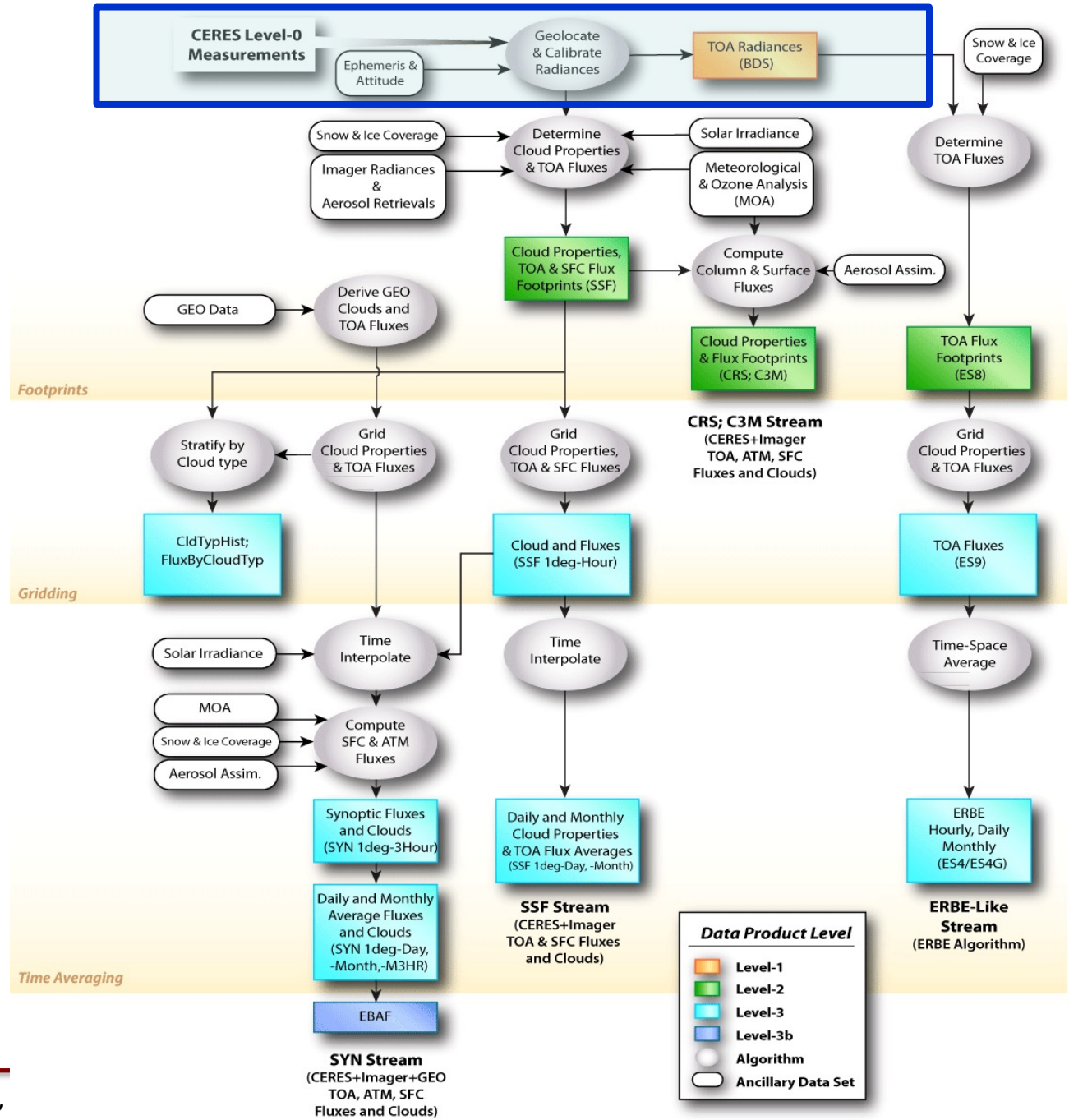
Libera Science Data Flow



Libera beyond L-1b

RBSP is the Radiation Budget Science Project

CERES Data Processing Flow



Libera Algorithm Theoretical Basis Document (ATBD)

Section	Product or Processing	ATBD content	Lead
1	L-1b Radiometer Radiances	Instrument calibration and operations	D. Harber
2	Geolocation	Radiometer and camera	S. Beland
3	L-1c Unfiltered Radiometer radiances	VIS and NIR	P. Pilewskie
4	L-1b Camera radiances	Instrument, calibration and operations	S. Schmidt
5	L-2x Cloud fraction	Adaptive thresholding + camera	S. Schmidt
6	ADMs for split channel	ADM formulation & binning	J. Gristey
7	L-2x TOA SW, VIS, NIR fluxes	Instantaneous foot print (limited regions); Scene ID with camera/VIIRS CF VIIRS & (new) ERBE ADMs	M. Hakuba
8	L-2 TOA Far-IR fluxes	Instantaneous foot print; includes ADMs	X. Huang
9	L-2 SUR fluxes SW, NIR, VIS	Computed TOA and SUR fluxes SSF; validation approach	X. Dong

Coordination Between *Libera* and RBSP

- Weekly meetings between LASP and RBSP
- Calibration and Validation working group oversees ground and on-orbit calibration activities. Interface between LASP, technical partners at Ball, NIST and SDL and the RBSP.
- The *Libera*/RBSP/ASDC Data Management Working Group oversees the production and distribution to the RBSP and ASDC of Libera level 1-b data and metadata
  - Meeting at NASA Langley Sep. 8-9
- The *Libera*/RBSP Operations Working Group will manage the Libera concept of operations before and during the year-1 Phase E operations effort.

All part of the *Libera Earth Radiation Budget Continuity Plan*

Libera Major Reviews and Key Milestones

Milestone	Acronym	Date	Convening Authority
Authorization to Proceed	ATP	6 Jul 20	-
System Requirements Review	SRR	22 Feb 21	SRB
Key Decision Point - B	KDP-B	30 Apr 21	SMD PMC
Preliminary Design Review	PDR	8-10 Feb 22	SRB
Key Decision Point - C	KDP-C	12 Apr 22	SMD PMC
Critical Design Review	CDR	Jun 23	SRB
Instrument Integration Review	IIR	Jan 25	SRB
Pre-Environmental Review	PER	Mar 25	SRB
Pre-Ship Review	PSR	Sep 25	SRB
Delivery to Spacecraft		Oct 25	-
Key Decision Point D	KDP-D	Oct 25	SMD PMC
Launch		2027	-
Key Decision Point E	KDP-E	2027	SMD PMC
Post Launch Assessment Review	PLAR	L+90d	SRB
Operational Transition Review	OTR	PLAR + 9mo	TBD

Libera Science Team

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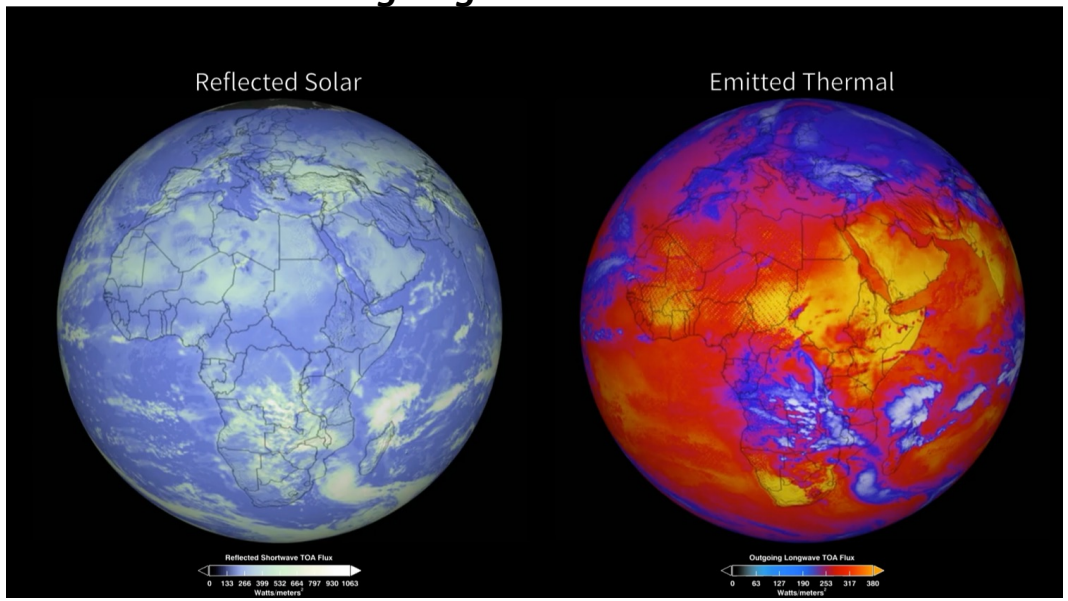
Sebastian Schmidt, Co-I	CU LASP	Jacqueline Russell	IC/UK
Tom Vonderhaar, Co-I	CSU	Martin Wild	ETHZ

Libera, Earth Venture Continuity-1 Mission

'Li-be-ra, named for the daughter of Ceres in ancient Roman mythology

Outgoing Earth Irradiance



Joint Polar Satellite System-3

Libera continues the 22-year CERES Climate Data Record for the Earth Radiation Budget (ERB).

- *Measures reflected solar and emitted terestrial radiation from Earth*
- *Provides fundamental climate information about the balance between incoming (from TSIS) and outgoing energy from Earth*
- *Continuity of this climate record over time reveals the signals of climate change – connects temperature trends to energy flow*

Libera is Innovative:

- *Uses state-of-the-art detectors with carbon nanotube technology, the blackest substance on Earth*
- *Adds a split-shortwave measurement to isolate where energy from the Sun is deposited in the Earth system*
- *Adds a wide-field-of-view camera to support split shortwave science*

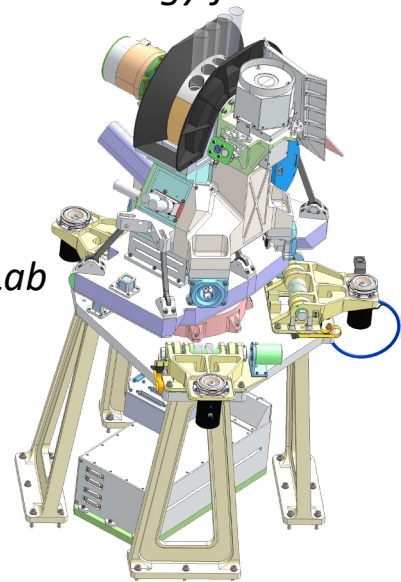
Partners:

- *LASP, Ball Aerospace, NIST Boulder, Space Dynamics Lab*
- *Science Team: CU, JPL, CSU, UA, UM, LBL*

Flight:

- *JPSS-3, 2027 launch; 5-year mission*

Critical Design Review in June 2023



Thanks!